

Commissioning of RHIC p-Carbon CNI Polarimeter¹

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Abstract. An innovative polarimeter based on proton carbon elastic scattering in the Coulomb Nuclear Interference (CNI) region has been installed and commissioned in the Blue ring of RHIC during the first RHIC polarized proton commissioning. The polarimeter consists of ultra-thin carbon targets and four silicon detectors. All elements are in a 1.6 meter target chamber. It worked very well as a pivotal tool during the commissioning. It demonstrated that the RHIC snake magnets rotate spin to the expected direction. The results also show that polarized proton beam has been accelerated in RHIC and the polarization is maintained up to 29 GeV.

For polarization monitoring during RHIC polarized proton operation, a fast and reliable polarimeter is required that produces a polarization measurement with a 10% relative error within a few minutes. The idea of using $\vec{p} + C$ elastic scattering in the Coulomb-Nuclear Interference region (CNI) was suggested for the fast polarimeter several years ago. It is attractive because a significant (4%) analyzing power is predicted over the entire RHIC range. The figure of merit, at the maximum analyzing power at $-t = 0.003 \text{ GeV}^2/c^2$, is excellent compared to other candidate processes. The sizable analyzing power, the large cross section and the advantages of a solid ribbon target make this process ideal for a fast primary polarimeter for RHIC.

An AGS Experiment (E950) has been done to measure the asymmetry in the $p\text{-}C$ CNI process at 21.7 GeV, which is in the RHIC injection energy range. The exper-

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imental results show that the recoil carbons from CNI scattering can be obtained with the Si detectors, and the asymmetry behavior follows the theory qualitatively [1]. A p -C CNI polarimeter was then installed in the Blue ring of RHIC and commissioned during the first RHIC polarized proton commissioning.

The RHIC p -C CNI polarimeter uses a carbon target, which is much simpler and cheaper than a hydrogen jet, and also easier to handle in the vacuum. Using a carbon target also results in the high luminosity required for fast polarization measurements. The very thin carbon target developed at IUCF [2] is crucial to the p -C CNI polarimeter: both for survival in the RHIC beam and to get the carbon nuclei out of the target in the CNI region where the recoil carbon carries only hundreds of keV kinetic energy. The target is only 100 atoms thick, which allows the slow carbon nuclei (150 keV) to escape and reduces the scattering rate to a level tolerable by detector electronics. It survives the beam due to its large surface to volume ratio. A potential disadvantage is that the number of carbon atoms can actually become depleted, so it is important to use the scattering time efficiently. However, this also works out well, with an expected lifetime of hours in the beam and measurements taking tens of seconds. The detail of the design of the RHIC p -C CNI polarimeter is given in Ref. [3].

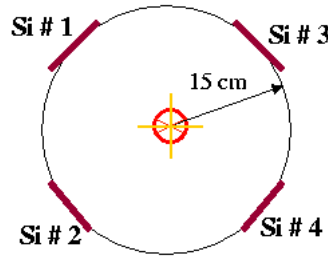


FIGURE 1. Cross section of the target chamber. Beam is going into the paper and hits the carbon target in the center of the beam pipe. The carbon target is $5.5\mu\text{g}/\text{cm}^2$ thick and $11.6\mu\text{m}$ wide.

In manipulation of polarization in RHIC, information on both vertical and horizontal components of beam polarization are needed. In addition, only one helical Siberian snake [4] has been installed this year. The stable spin direction is in the horizontal plane with snake on and in the vertical direction with snake off. The injected beam from AGS is in the vertical direction. It is necessary to have the snake off during injection and then have it adiabatically turned on so that beam polarization follows the stable spin direction and turns from vertical to horizontal. Four silicon detectors were installed obliquely, 15 cm from the target, as shown in Fig. 1, in order to measure both transverse components. When using these two pairs for either vertical or radial components, the analyzing power will drop by a factor of $\cos 45^\circ = \sqrt{2}/2$. These detectors provide measurements of both vertical polarization (left-right) $= ((1+2)-(3+4))$, and radial polarization (up-down) $= ((1+3)-(2+4))$, with the detectors numbered as in Fig. 1.

The commissioning was done by injecting 6 proton bunches with alternating polarization, for example, $\uparrow\downarrow\uparrow\downarrow\uparrow\downarrow$. There were about 3×10^{10} protons per bunch

with a separation of about $2\mu s$. Injection energy was 24.3 GeV ($G\gamma = 46.5$). The AGS E950 readout, FERA ADCs and TDCs, were used for this run. The trigger was a coincidence between the beam bunch crossing timing and any delayed Si strip hits. Triggers were rejected if no silicon detector strip was above threshold.

The identification of a carbon band is shown in Fig. 2 as energy vs. time-of-flight plots, for each of 12 strips on one silicon detector. All 48 silicon strips worked beautifully. In fact, there is very little background as shown for the reconstructed mass in Fig. 3. An alpha peak can be seen clearly (presumably quasi-elastic p-alpha scattering). The energy was calibrated using observed carbon and alpha mass peaks. The commissioning showed that p -C CNI scattering can be identified with little background.

When the data are combined as discussed above to measure vertical and radial polarization, the vertical polarization of the injected beam was observed (see plot A of Fig. 4). Reversing the injected beam polarization resulted the beam polarization reversed. As a cross-check, unpolarized beam was injected and zero polarization was observed in RHIC. Based on the preliminary analyzing power for p -C CNI polarimeter and AGS internal polarimeter, the polarization at RHIC injection was about 19 ± 1 % (statistical error only), which was less than the polarization measured at the AGS extraction, 33 ± 1 % (statistical error only). The polarization at injection is sensitive to the beam energy and betatron tunes. Due to the limited running time, no effort was devoted to explore the tune space and injection beam energy during the commissioning.

With one snake in the ring, it is necessary to turn it on after beam injection, so that the stable spin direction is then turned into the horizontal plane from vertical

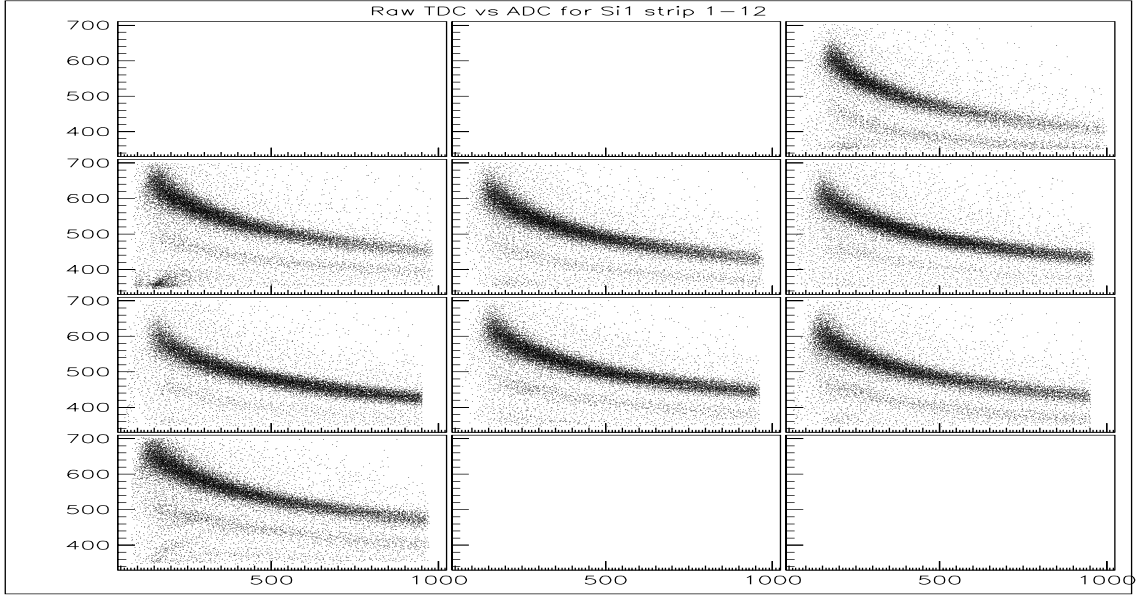


FIGURE 2. Scatter plot between the ADC values on the horizontal axis and the time of flight on the vertical axis for Si detector 1. Only center eight strips were used in the analysis.

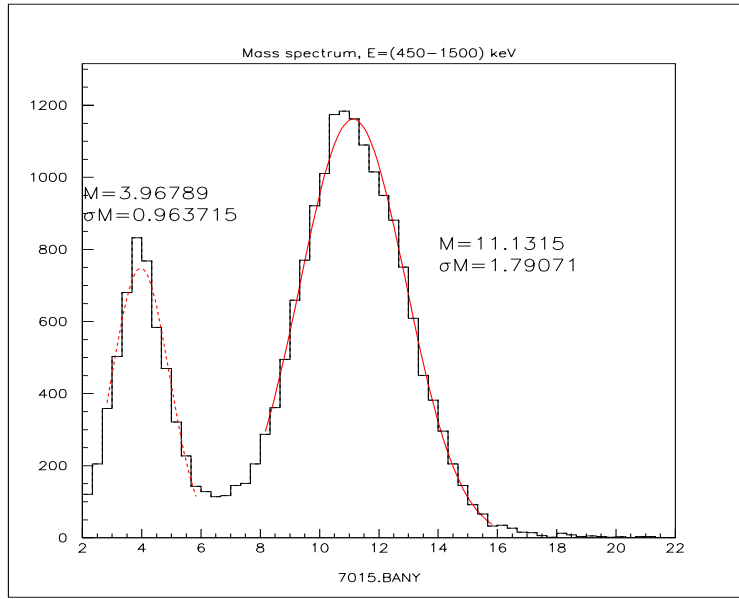


FIGURE 3. Mass spectrum. The horizontal axis is in the unit of GeV and vertical axis gives the event counts.

direction. The angle in the horizontal plane is determined by the beam energy, snake rotation axis and location of observation point relative to the snake. The polarimeter can only measure either vertical or radial components, so the beam energy was properly chosen to get radial component at the polarimeter. The expected radial polarization was observed after the snake was adiabatically turned on (see plot B of Fig. 4). This proved that the snake rotated the spin as expected. Polarized beam was accelerated to 25.1 GeV ($G\gamma = 48$), past several resonances including a strong resonance with a strength of 0.02. Measured polarization reversed direction radially as expected and showed similar magnitude (see plot C of Fig. 4). Polarized beam was then accelerated to 29.2 GeV ($G\gamma = 55.7$), past many more resonances including two more strong resonances, and again was measured with the expected direction and no noticeable polarization loss (see plot D of Fig. 4). When polarized beam was accelerated to 31.6 GeV ($G\gamma = 60.3$), just above a much stronger resonance with strength of 0.07, no significant polarization was measured (see plot E of Fig. 4). Most likely the depolarization is due to the strong snake resonances because the vertical closed orbit was too large and the betatron tune was moving around during acceleration. No time was spent in the commissioning to correct them. Next year, our goal is to control the vertical betatron tune to better than .005 and the vertical closed orbit to better than 0.5 mm rms. Both of these requirements will be a major focus for the preparations for next run but are quite feasible based on the operational experience with gold beams.

With the E950 electronics, there was considerable dead time: readout of a full buffer took 1.5s. Next year with 60 bunches and higher bunch intensity, the DAQ system will be upgraded to wave form digitizer (WFD) readout, so there will be

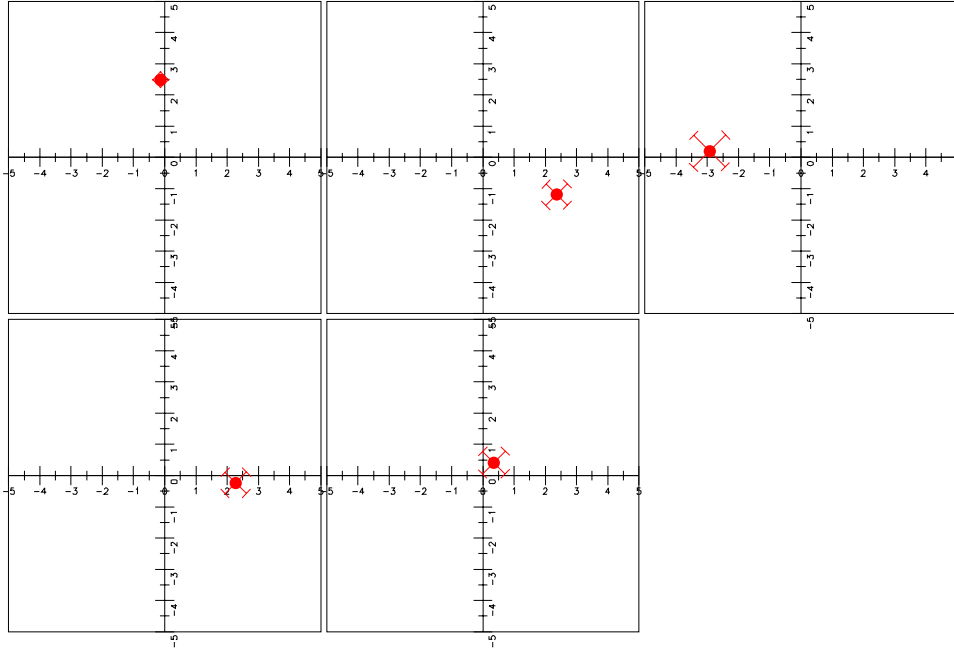


FIGURE 4. Plot of polarization vectors at various energies. Both horizontal and vertical axes are in units of asymmetry $\times 10^{-3}$. Top row from left to right: A) $G\gamma = 46.5$ and snake off; B) $G\gamma = 46.5$ and snake on; C) $G\gamma = 48$ and snake on; bottom row from left to right: D) $G\gamma = 55.7$ and snake on; E) $G\gamma = 60.3$ and snake on. The error bars reflect the fact that the asymmetries were derived from the 45° detectors.

no dead time. A prototype WFD module was tested during the commissioning run and worked as expected.

We have completed a successful test of a new relative polarimeter, which measures proton-Carbon elastic scattering at small angles(CNI region). The first successful use of a full helical Siberian snake was demonstrated. The p -C CNI polarimeter is ideal for high energy proton polarimetry: fast measurement, low cost and compact size. Another p -C CNI polarimeter will be installed in the Yellow ring before next run. To accommodate the higher beam intensity next year, the DAQ system will be upgraded by utilizing the WFD readout.

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